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PROTECTION OF PRODUCTION WELL EQUIPMENT IN IN
SITU COMBUSTION OPERATION
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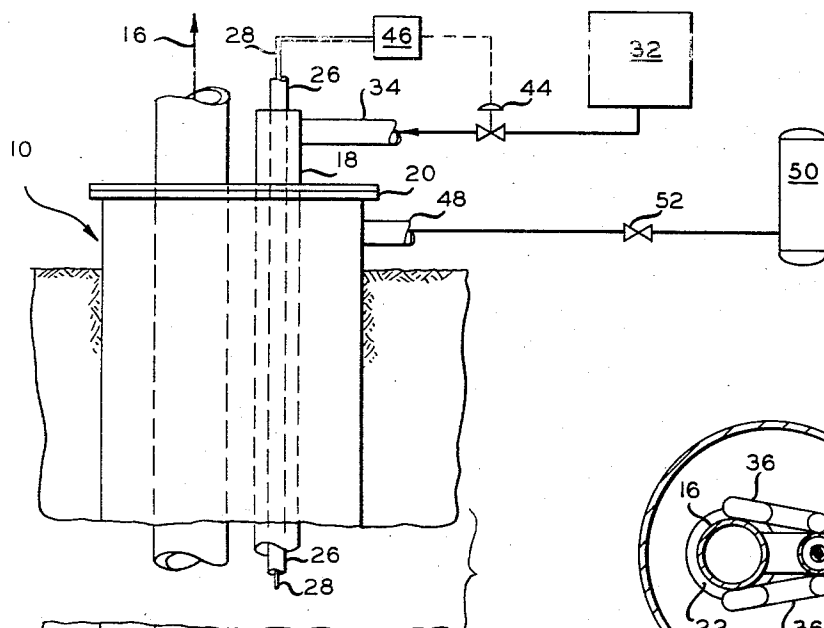
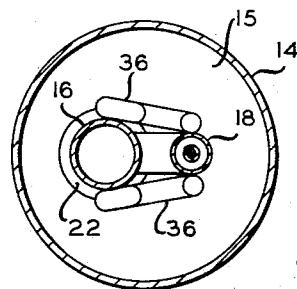


FIG. 2

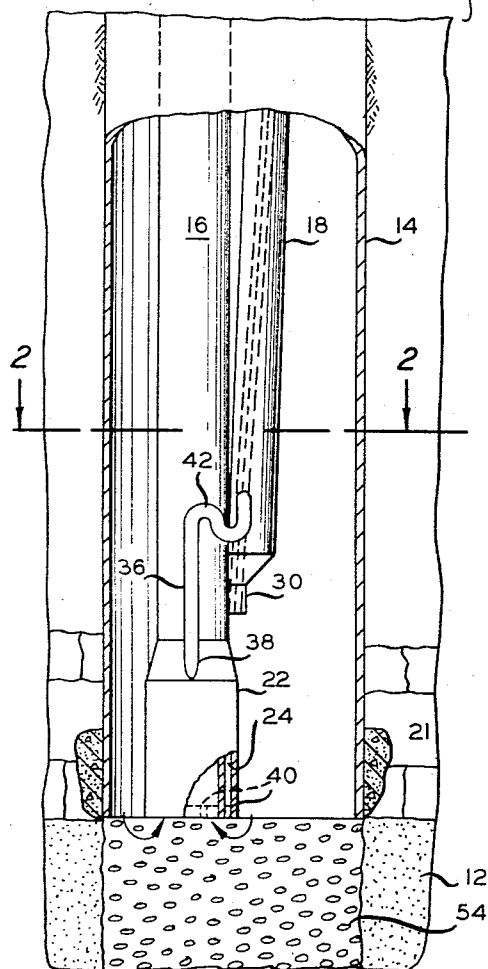


FIG. 1

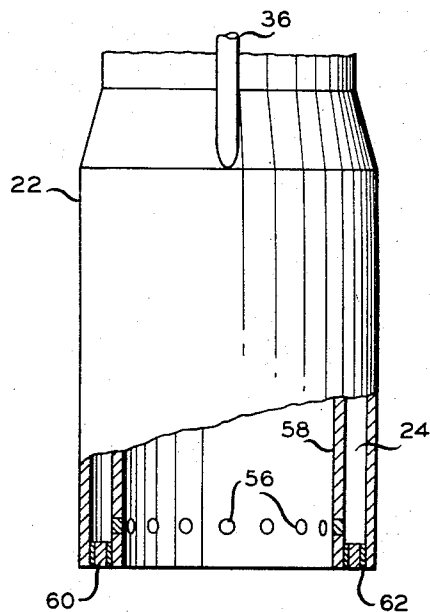


FIG. 3

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1

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PROTECTION OF PRODUCTION WELL EQUIPMENT IN IN SITU COMBUSTION OPERATION

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ABSTRACT OF THE DISCLOSURE

In preventing overheating and destruction of downhole equipment in a production well in an in situ combustion operation producing oil in hot vapor form from an oil stratum, a jacketed tubing shoe is positioned on the lower end of the tubing string adjacent the oil stratum and fluid coolant (water) is injected into said shoe and vented from the lower end thereof into the produced hot fluid to cool same to a safe temperature. A temperature sensing means is positioned adjacent the stratum or the tubing shoe and communicates with a recorder and controller at ground level to operate control means in the fluid coolant line in response to sensed temperature.

This invention relates to a process and apparatus for protecting downhole production well equipment in an in situ combustion operation in a carbonaceous stratum and for facilitating the recovery of hydrocarbons from such a well.

The production of hydrocarbons from carbonaceous strata by in situ combustion is an accepted process in the oil industry. In such a process, a combustion zone or front is established in the carbonaceous material around a well therein and the resulting combustion zone is moved thru the stratum to one or more offset wells therein either by direct drive or by reverse drive. In a direct drive process, air is injected thru the ignition well so as to drive the combustion front toward the offset well or wells and hydrocarbons are produced thru the offset wells. As the combustion front approaches the proximity of the production wells, extremely high temperatures are produced in the production well which at times exceed 2000° F. In a reverse drive process, air is injected thru the offset wells to feed the combustion zone around the ignition well and the combustion front is moved toward the air injection wells, traveling in a reverse direction to the air. In this type of process, the ignition well serves as the production well and receives high temperature gases during the entire operation. Also, during the ignition of the carbonaceous material in either type of process the temperatures in the ignition well become excessive and cause damage to the well. Excessive temperatures are also produced by fires in the production well resulting from injected air bypassing the combustion front in the stratum and occurring in the produced gases. In field operation it has been found that the oxygen concentration at times reaches 8–10 percent. In several counterflow or reverse combustion operations in the field, hot fluids have destroyed the tubing in and the effectiveness of the production well.

This invention is concerned with an apparatus and process for controlling production and ignition well temperatures so as to facilitate the production of hydrocarbons by in situ combustion. Accordingly, it is an object of the invention to provide a process and apparatus for controlling downhole temperatures in a production or ignition well in an in situ combustion operation. Another object is to provide an apparatus and process for automatically controlling downhole temperatures in a production or ignition well in an in situ combustion operation. A further object is to provide method and means of preserving

2

hydrocarbons in a production well produced by in situ combustion of a carbonaceous stratum. Other objects of the invention will become apparent to one skilled in the art upon consideration of the accompanying disclosure.

A broad aspect of the invention comprises moving a combustion zone thru a carbonaceous stratum between a production well and at least one injection well by feeding combustion supporting gas to the burning zone so as to produce hot effluent, hydrocarbons, and combustion gases in the production well; passing the effluent stream thru a wellbore pack of refractory aggregates within the stratum and thru a production string leading from the proximity of the pack thru the wellhead to a production line; injecting water into the effluent stream intermediate the pack and the lower end of the production string so as to maintain bottom hole temperature below that at which combustion of hydrocarbons can take place in the presence of the O₂ which bypasses the combustion zone; and recovering produced hydrocarbons from the effluent stream at ground level. Another aspect of the invention comprises sensing the temperature in the proximity of the pack and controlling the water injection rate in response to the sensed temperature to maintain a safe temperature in the production well adjacent the pack in the range of about 500–800° F.

A further aspect of the invention comprises utilizing the foregoing techniques in an ignition well during ignition of a carbonaceous stratum wherein fuel admixed with a mass of refractory aggregates is burned with injected air in the stratum adjacent the ignition well and the injection of air is continued so as to ignite and burn the surrounding stratum. During this ignition a reservoir of water is maintained adjacent the aggregates, said water being releasable at a predetermined ambient temperature in the range of about 500–800° F., so that the water is released when the ambient temperature reaches said range. The temperature is controlled thereafter by sensing the ambient temperature and regulating the water flow rate into the well in accordance with the sensed temperature. A further refinement of the process comprises injecting an uncombustible and non-combustion-supporting gas into the casing-tubing annulus of the well to prevent formation therein of a combustible mixture of gases which might result from the bypassing of oxygen around the combustion front and occurrence of the free oxygen in the wellbore along with produced hydrocarbons. This mixture of oxygen and hydrocarbons might move up the casing-tubing annulus and be ignited so as to explode and blow the wellhead off.

The apparatus aspects of the invention comprise a production tubing string within a casing in a production well penetrating a carbonaceous stratum to be produced by in situ combustion; a jacketed tubing shoe on the lower end of the tubing string having inlet means and outlet means for circulating a coolant therethru and into the well ambient adjacent the stratum for cooling the end of the tubing string and also the produced fluids entering the tubing string; a coolant tubing string within the casing extending from the wellhead to the proximity of the tubing shoe; a conduit means connecting the lower end of the coolant tubing string with the inlet means of the shoe; a macaroni tubing string within the coolant tubing string providing an annulus therewith for coolant and carrying internally a thermocouple cable extending from outside the wellhead thru the lower end of the coolant string; and a temperature sensing means, such as a thermocouple, on the lower end of the cable outside of the tubing strings and within the casing. A source of coolant is connected with the coolant tubing string by conduit means having a flow control valve therein and a temperature controller is operatively connected with the thermocouple cable at ground level and operatively

3

connected with the valve in the coolant conduit for increasing and decreasing flow of coolant as the sensed temperature increases and decreases, respectively, from a predetermined level or value. A refinement of the invention comprises a low-melting alloy plug in the outlet means of the jacketed tubing shoe for preventing flow of coolant until downhole temperature reaches at least the melting point of the alloy. Another aspect of the inventive apparatus lies in providing a tray in the conduit means connecting the lower end of the coolant tubing string with the jacketed shoe on the end of the production string. A further refinement of the invention comprises a wellbore pack of refractory aggregates within the stratum subjacent the jacketed shoe on the end of the production string substantially filling the wellbore to the top of the stratum. Also, a supply reservoir of purge gas with a conduit connecting the same to the casing-tubing annulus is provided for maintaining purge gas in the annulus.

A more complete understanding of the invention may be had by reference to the accompanying schematic drawing of which FIGURE 1 is an elevation in partial section of a production well penetrating a carbonaceous stratum; FIGURE 2 is a cross section taken in the line 2—2 of FIGURE 1; and FIGURE 3 is an elevation in partial section of a tubing shoe applicable to the apparatus of FIGURE 1.

Referring to FIGURE 1, a production well 10 penetrating a carbonaceous stratum 12 is provided with a casing 14 extending to the top of the stratum, and with a production tubing string 16 and a coolant tubing string 18. The various tubing strings extend thru wellhead 20 and terminate in the bottom of the well. Casing 14 is cemented to the surrounding formation at its lower end as shown at 21.

Production tubing string 16 connects with a production line, not shown, leading to separation and refining equipment. A jacketed tubing shoe 22 is positioned on the lower end of the production string and is provided with annular coolant space 24 and inlet means and outlet means for coolant, subsequently identified.

Coolant tubing string 18 carries internally a macaroni tubing 26 which in turn carries internally a thermocouple cable 28 extending from above ground thru the lower end of tubing string 18 and terminating in a thermocouple 30. Coolant such as water or inert gas from source 33 passes thru line 34 into the annulus within string 18. The lower end of coolant string 18 and macaroni tubing 26 are welded to production tubing string 16 and conduit means 36 provides communication for coolant between tubing 18 and the inlet 38 of tubing shoe 22 to provide flow of coolant into the tubing shoe. Circulation of coolant thru space 24 is provided by positioning outlet holes 40 in the lower end of the shoe. Conduit 36 includes a suitable trap such as goose-neck 42 to prevent emptying of the coolant tubing string completely when the flow of coolant is terminated.

To provide for automatic regulation of temperature in the bottom of the well adjacent tubing shoe 22, a motor valve 44 is positioned in line 34 intermediate supply tank 32 and tubing 18 and a temperature controller 46 sensitive to the temperature registered by instrument 30, is in control of motor valve 44 so as to increase the opening of this valve when the temperature rises and decrease the opening thereof when the temperature falls with respect to a predetermined temperature level such as one in the range of 500–800° F. It has been recognized that with concentrations of oxygen in the produced effluent from in situ combustion operations, the ignition point of the effluent is substantially above the ignition temperature when admixed with air so as to provide higher concentrations of oxygen.

A line 48 leads from a supply of inert gas in tank 50 to the annulus inside casing 14 and is provided with a control valve 52.

4

The bottom of well 10 within stratum 12 is packed with refractory aggregates 54. These aggregates are formed of ceramic materials such as broken firebrick and are preferably porous, although they may be formed of non-porous material such as alumina or mullite pebbles capable of withstanding high temperatures. In one ignition technique, the porous aggregates are soaked with heavy oil, such as asphaltic oil, which is burned as fuel to heat the surrounding wellbore to combustion supporting temperature. In another ignition technique, impervious aggregates are mixed with charcoal aggregates which are soaked with heavy oil whereby the charcoal and oil are burned during the ignition phase of the operation and the refractory aggregates remain in the wellbore as the pack shown.

The function of the pack comprises preventing sand infiltration into the wellbore and any material in aggregate form which withstands temperatures up to 1500 to 2000° F. is suitable for the wellbore pack.

Referring to FIGURE 2, this plan view shows the relationship of casing 14 to the strings of tubing therein providing the annulus 15 into which purge gas is injected to prevent accumulation of a combustible gaseous mixture during the in situ combustion operation. Conduits 36 on opposite sides of the tubing strings 16 and 18 are shown in their positional relationship.

Referring to FIGURE 3, jacketed shoe 22 is similar to that of FIGURE 1 but shows another embodiment of the arrangement of outlet holes for coolant fluid. Holes 56 are radially positioned holes in pipe 58 which is an extension of the end of production tubing string 16. These holes direct coolant radially inwardly into the upwardly flowing production effluent. Vertical holes 60 in ring 62 provide for flow of coolant downwardly into pack 54. Holes 56 and 62 are filled with a low-melting point alloy at the start of the operation (ignition) so that cooling water in the coolant string and in annulus 24 cannot flow into the wellbore and hinder ignition. The alloy in holes 56 and 60 can be fabricated of any combination of metals which provide a suitable melting point such as one of about 700–1000° F. or any selected melting point which adequately protects the downhole equipment during ignition of the stratum. The alloy is formed of combinations of lead, tin, bismuth, and antimony which are well-known and have suitable melting points for the intended purpose when properly composited.

The temperature of the produced downhole environment or ambient adjacent or close to the cooling shoe 22 is sensed by thermocouple 30 and the output from this thermocouple thru instrument 46 is used to control, manually or automatically, the rate of water injection thru string 18 to cool the produced fluids in production string 16 to a prescribed temperature. The maximum temperature allowed for protection of the downhole equipment is about 800° F. when using normal steel, such as American Petroleum Institute grade J–55, for tubing and casing.

The bottom of the tubing strings are made so that thermocouple 30 accurately measures the temperature of the cooled production fluid. To enhance this operation, a good heat transfer fluid such as mercury is used in the bottom of macaroni tubing 26 and the bottom of the macaroni tubing is welded to the production tubing 16 in the vicinity of thermocouple 30. The cooling water tubing at this point is separated from the production tubing with insulating material such as asbestos (not shown). Thermocouple 30 is located an adequate distance above cooling water jacket 22 and below cooling water tubing 18 to minimize the effect of heat transfer to these sinks.

Thermocouple cable 28 is placed in separate macaroni tubing 26 so that it can be readily removed for inspection and repair. Macaroni tubing string 26 is placed inside of cooling water tubing 18 to protect the thermocouple cable from excessive temperatures.

5

In order to facilitate running tubing strings **16** and **18** and macaroni string **26**, separately, joints not shown are provided in tubing string **18** and macaroni string **26** above the welds fastening same to production string **16** and in the proximity of the welds. Each tubing string thus can be run separately or the production and cooling water strings can be run simultaneously and the macaroni string separately.

In one embodiment of the invention, the lower several hundred feet of thermocouple cable **28** comprises Ceramo thermocouple wire which withstands temperatures up to at least 800° F. Teflon insulated thermocouple wire with braided covering connects with the Ceramo section and extends at least thru the wellhead, with any type of thermocouple wire connecting same with instrument **46**.

Cooling shoe **22** in one installation is fabricated of J-55 steel pipe in a 17' long section. Tubing string **16** has a 3.5" O.D. and a 3.0" I.D. Water jacket **22** has a 4.5" O.D. and a 4.0" I.D., thereby providing a quarter-inch annulus **24** within the cooling shoe for circulation of coolant. Water tubing string **18** has a 2.875" O.D. and a 2.44" I.D.

Macaroni tubing **26** has a 1.315" O.D. and a 1.0" I.D. Jacket **22** is welded to the outside of tubing **16** at the upper end by an orange peel weld.

In operation, stratum **12** is ignited adjacent pack **54** as described above and air is injected thru the stratum from one or more offset injection wells so as to feed the combustion zone thus established and cause same to move radially outwardly from well **10**. During this period hot production effluent enters well **10** downhole thru the pack **54** and is produced thru production string **16**. At any time during this operation when the temperature downhole exceeds the melting point of the alloy plugs in cooling shoe **22**, these plugs melt and flow out thereby releasing water into the effluent and into pack **54** for the purpose of cooling same and controlling the maximum temperature which prevents combustion and/or destruction of the downhole equipment.

Certain modifications of the invention will become apparent to those skilled in the art and the illustrative details disclosed are not to be construed as imposing unnecessary limitations on the invention.

We claim:

1. Apparatus comprising in combination:

- (1) a well extending into a permeable carbonaceous stratum provided with a casing extending from a wellhead at ground level to said stratum;
- (2) a tubing string within the casing of (1) extending thru said wellhead to said stratum;
- (3) a jacketed tubing shoe on the lower end of the tubing string of (2) having inlet means in an upper

6

section and an outlet means in a lower section for fluid coolant;

(4) a coolant tubing string within said casing extending thru said wellhead to the proximity of the tubing shoe of (3);

(5) conduit means connecting the lower end of the tubing string of (4) with the inlet means of (3);

(6) a macaroni tubing string within the tubing string of (4) providing an annulus therewith and carrying internally a thermocouple cable extending from outside said wellhead thru the lower end of the tubing string of (4); and

(7) temperature sensing means on the lower end of the cable of (6) outside of the tubing strings of (2), (4), and (6) and within the casing of (1).

2. The apparatus of claim 1 including:

(8) a source of coolant connected by conduit with the coolant tubing string of (4) having a flow control valve therein; and

(9) a temperature controller operatively connected with the cable of (6) and operatively connected with the valve of (8) so as to increase and decrease flow of coolant as the sensed temperature increases and decreases, respectively, from a predetermined value.

3. The apparatus of claim 2 including a trap in the conduit means of (5) for preventing coolant flow when the valve of (8) is closed.

4. The apparatus of claim 1 including a low-melting point alloy plug in the outlet means of (3) for preventing flow of coolant until downhole temperature reaches at least said melting point.

5. The apparatus of claim 1 including a wellbore pack of refractory aggregates within said stratum subjacent the shoe of (3) substantially filling said wellbore to the top of said stratum.

6. The apparatus of claim 1 including a source of purge gas connected by conduit with the tubing-casing annulus for injecting a non-combustible gas into said annulus to prevent formation therein of a combustible mixture.

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